AIRS impact on tropical cyclone forecasting in the GEOS-5

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Outline

Previous work - AIRS impact on GEOS-5 v2:

- Global AIRS impacts in all seasons and on mid latitude dynamics
- Tropical cyclones over all basins and different years
- Always found consistent results on improvement of analysis consequent to ingestion of cloudy retrievals instead of clear-sky radiances.
- Improved analyses caused improved forecast track

QUESTION: were the results good because the representation of TCs in the previous GEOS-5v2 was not optimal?

- Tropical Cyclones in 2010 with GEOS-5.7p2
- Conclusions, ongoing and future work
- Acknowledgements

Impact of Clear-sky Radiances versus Quality Controlled cloudy Retrievals (AIRS v5)

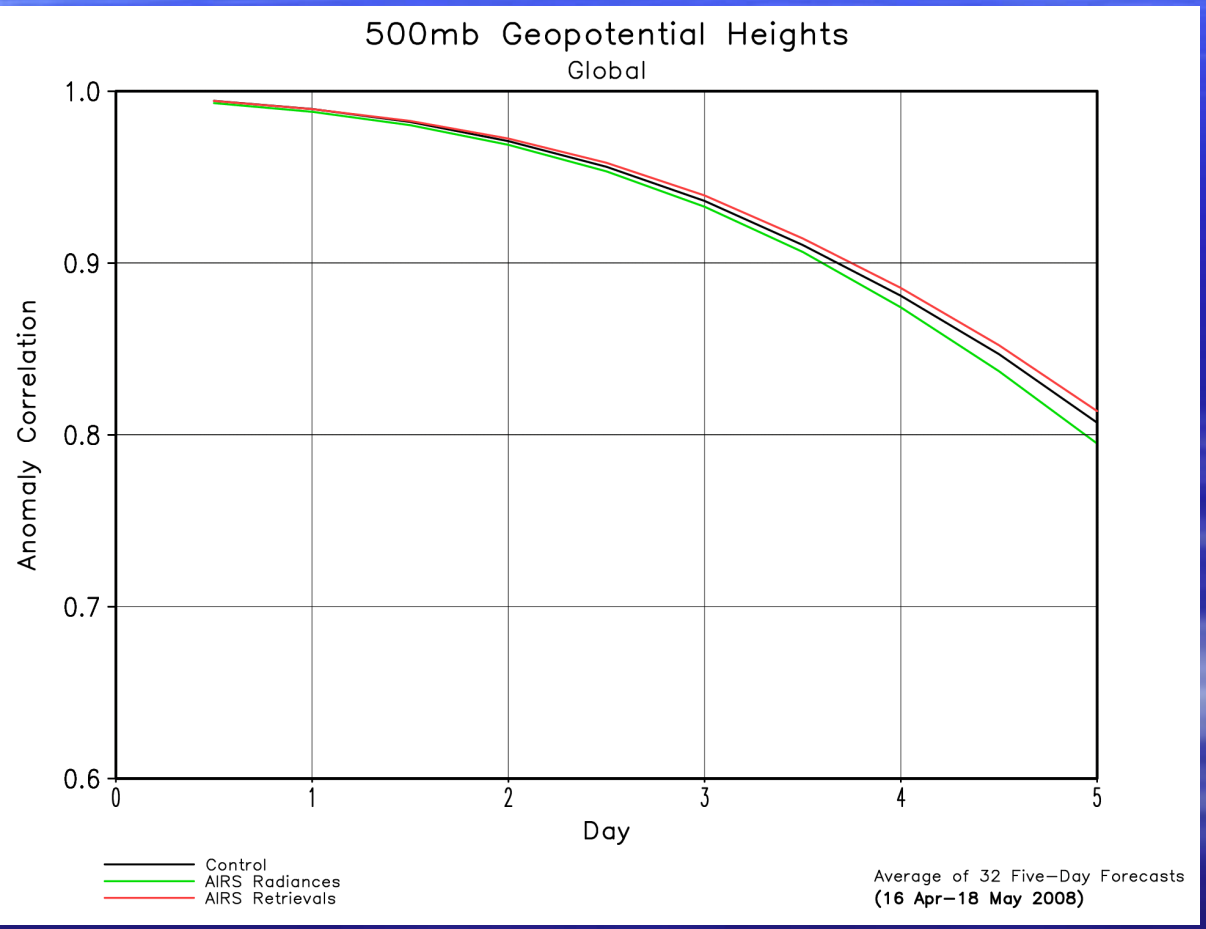
- A small fraction of AIRS data is still retained in operational weather systems, where the only AIRS data assimilated are radiance observations of channels unaffected by clouds. This imposes a severe limitation on the horizontal distribution of the data particularly with respect to TC initialization
- A poor TC initialization is detrimental to the forecast, regardless of the intrinsic abilities of the model
- Susskind et al (2011) document the AIRS version 5 retrieval algorithm. Key elements are the use of information from partly cloudy areas and the ability *to generate case-by-case and level-by-level error estimates and use them for quality control*
- This team has been performing a very large number of experiments, comparing AIRS v5 retrievals and radiances in all seasons and different years, looking at both global impacts and Tropical Cyclones

AIRS experiments settings

- **PREVIOUS EXPERIMENTS**: GEOS-5 v2 (~ MERRA)
- Periods chosen: Jan 2003 (active boreal winter); 8/10/06 to 9/15/2006 (NAMMA), 10/15/2005 to 11/15/2005 (Active TC Atlantic season), 4/15/2008 to 5/15/2008 (TC Nargis), 7/15/2010-8/31/2010 (Pakistan floods)
- **ALL** results in the GEOS-5v2 show larger impact of v5 retrievals versus radiances on global skill, on TCs, and on precipitation

- **NEW EXPERIMENTS**: July August September October 2010 with GEOS-5 v7.2
- AIRS RET: Assimilating all obs plus AIRS version 5 retrievals added as temperature profiles
- AIRS RAD: Assimilating all obs plus AIRS clear-sky radiances
- Forecasts at 0.25 (and/or 0.5 degrees previously)
- Period chosen: July-Aug-Sept-Oct 2010

Example: GEOS-5 v2 **Boreal Spring** (2008) Conditions: ***global impact*** of AIRS v5 retrievals vs. clear-sky radiances



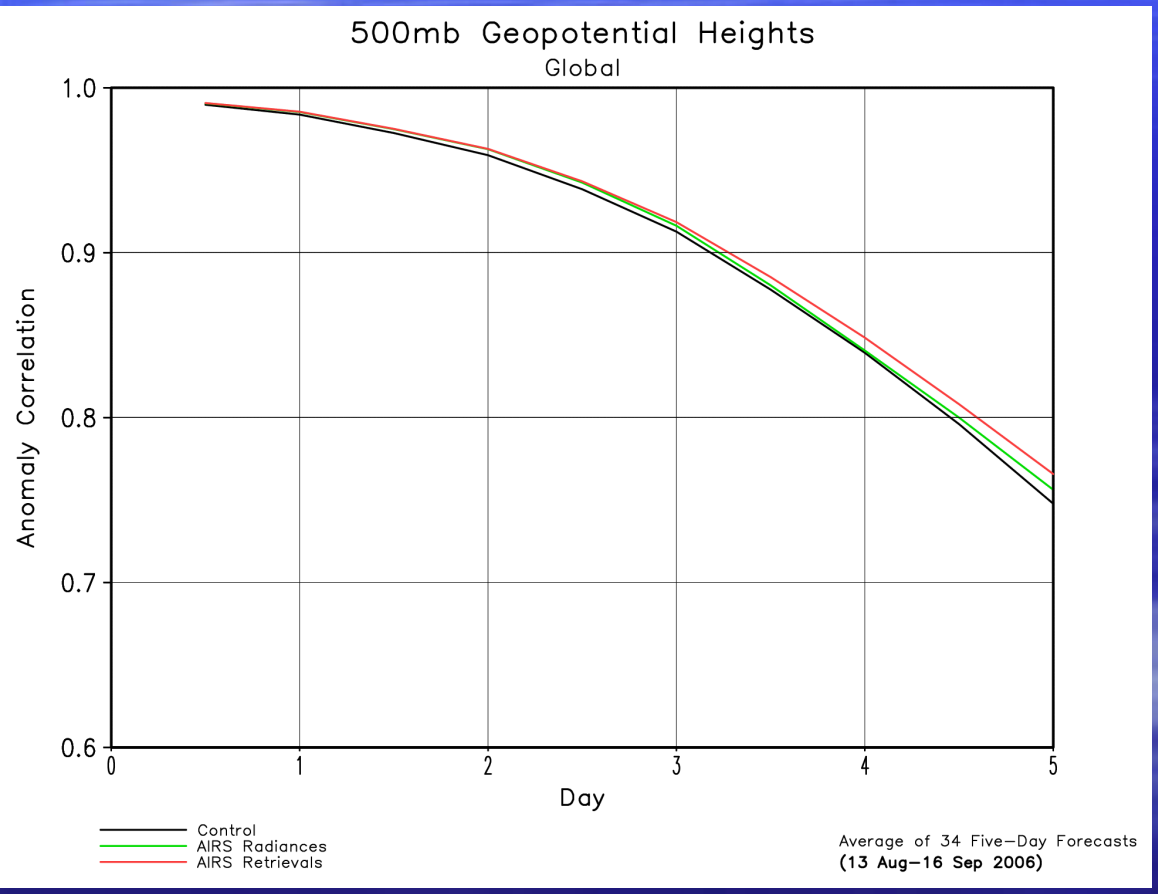
Positive global impact of AIRS retrievals (red).

Negative impact of AIRS clear-sky radiances (green).

In addition, representation of individual weather systems in the tropics are strongly impacted by AIRS.

Anomaly Correlations computed from 90S to 90N

Example of GEOS-5 v2 study of AIRSv5 global impact in **Boreal Summer** (2006) conditions: cloudy retrievals vs. clear-sky radiances



Strong global impact of AIRS retrievals (red).

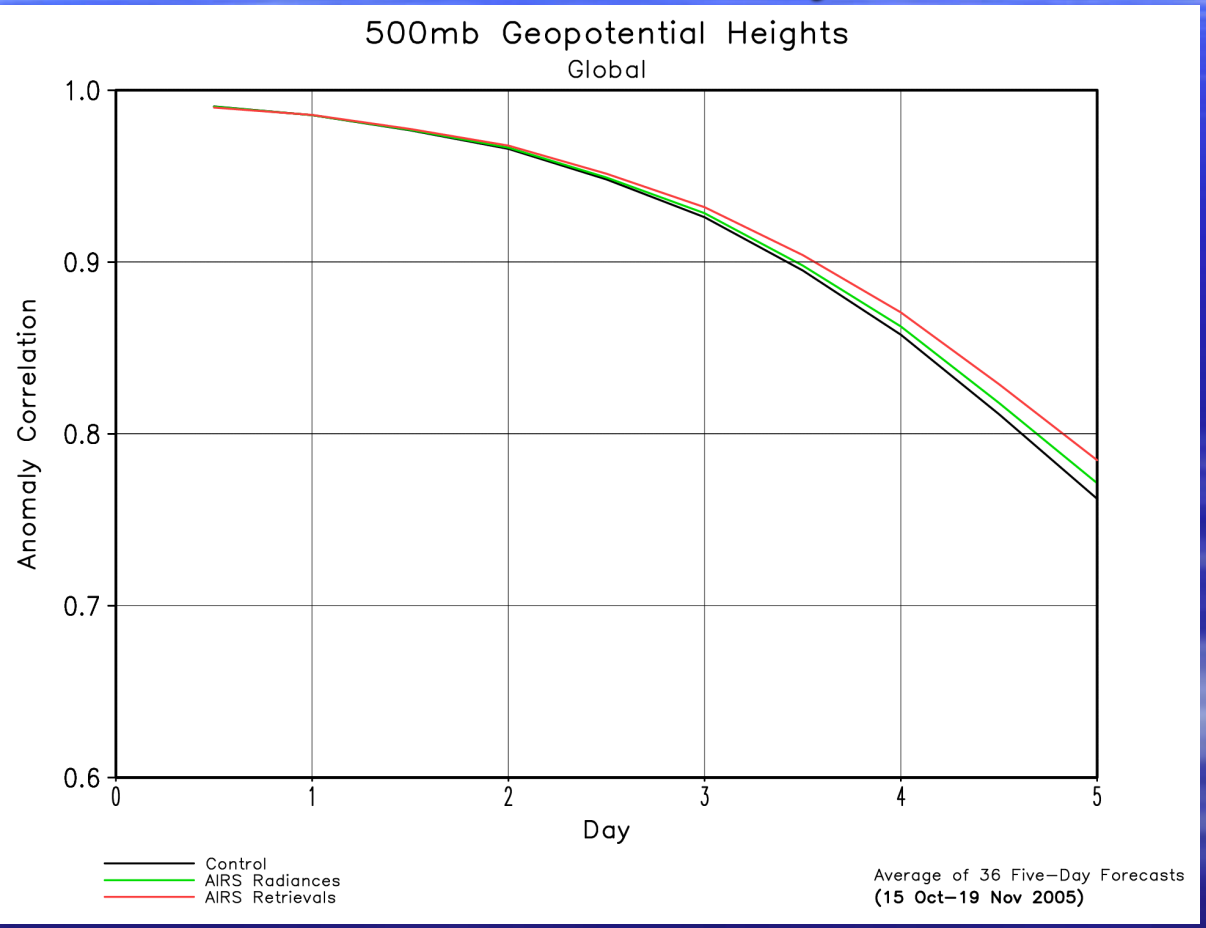
Smaller impact of AIRS clear-sky radiances (green).

In addition, representation of individual weather systems in the tropics are strongly impacted by AIRS.

Consistent results obtained for **Summer 2010**

Anomaly Correlations computed from 90S to 90N

GEOS-5 v2 **Boreal Fall** Conditions: ***global impact*** of AIRSv5 cloudy retrievals vs. clear-sky radiances



Strong Positive global impact of AIRS retrievals (red).

Smaller positive impact of AIRS clear-sky radiances (green).

In addition, representation of individual weather systems in the tropics are strongly impacted by AIRS.

Anomaly Correlations computed from 90S to 90N

Published AIRS impact study on tropical cyclone Nargis (2008) emphasizes the difficulty of analysing TCs over the Indian Ocean and compares performance of AIRS clear-sky radiances against cloudy retrievals.

- Work published in 2009 shows improvements in the GEOS-5 DAS and forecasting model consequent to assimilation of AIRS-derived information in CLOUDY areas. Case chosen: catastrophic cyclone Nargis which hit Burma causing devastating loss of life
- Tropical Cyclones in the Northern Indian Oceans are extremely difficult to analyze: operational global analyses often do not represent these cyclones' position (or even the TCs' very existence) accurately. Forecasts are penalized by these poor analyses

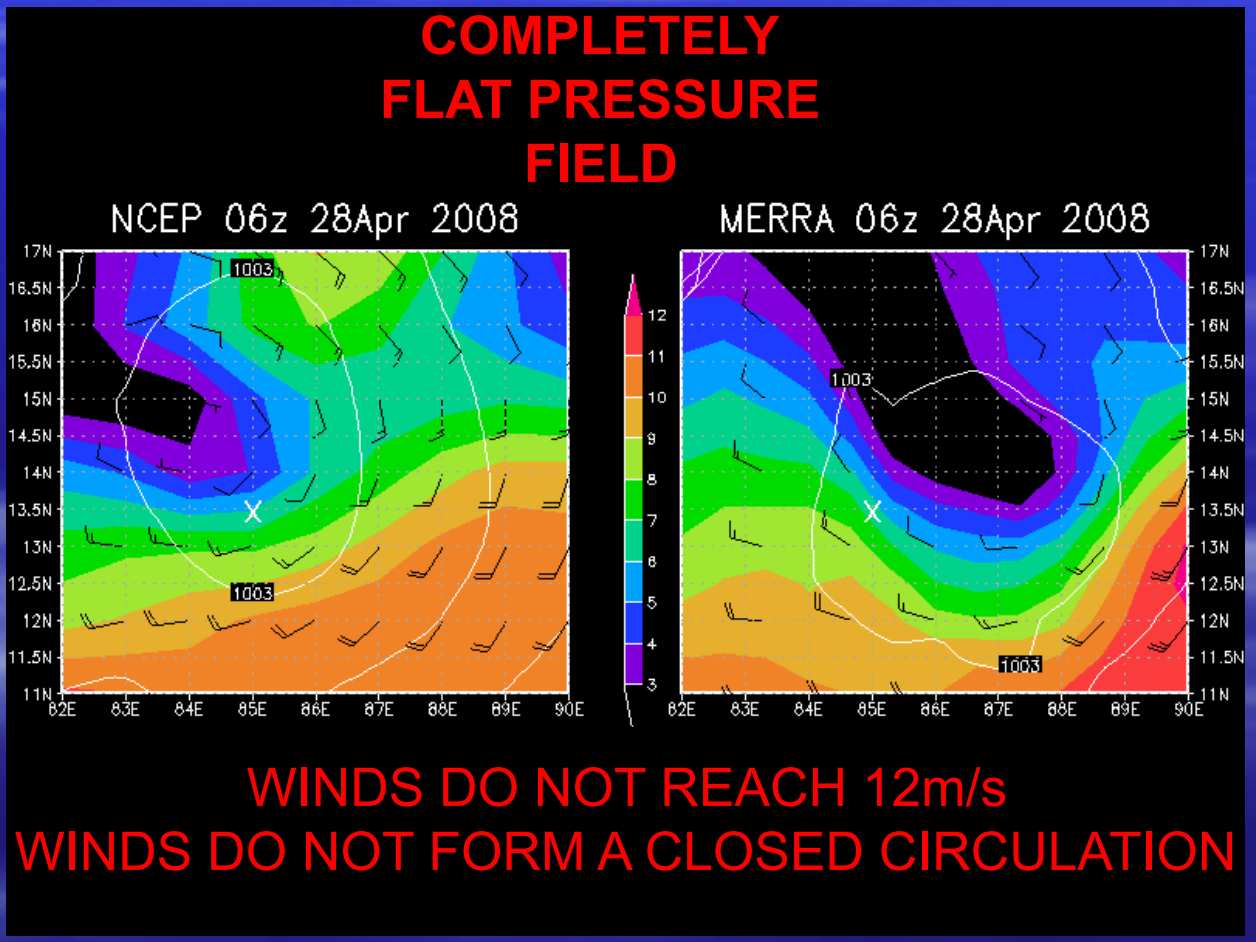
Reale, O., W. K. Lau, J. Susskind, R. Rosenberg, E. Brin, E. Liu, L.P. Riishojgaard, M. Fuentes, R. Rosenberg, 2009: AIRS impact on the analysis and forecast track of tropical cyclone Nargis in A global data assimilation and forecasting system.
Geophys. Res. Lett., 36, L06812, doi: 10.1029/2008GL037122

Complete miss of TC Nargis (2008) in both operational NCEP and MERRA analyses at a time when is declared having **hurricane-level winds** by the JTPC and IMC

800x600km
Contours
every 1hPa

WINDS DO
NOT FORM
A CLOSED
CIRCULATION

**COMPLETELY
FLAT PRESSURE
FIELD**

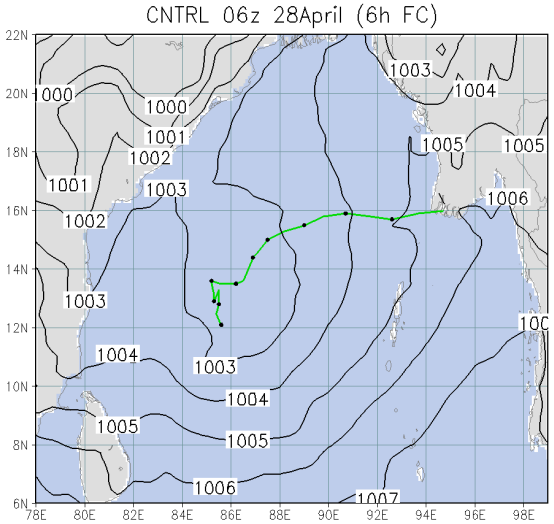


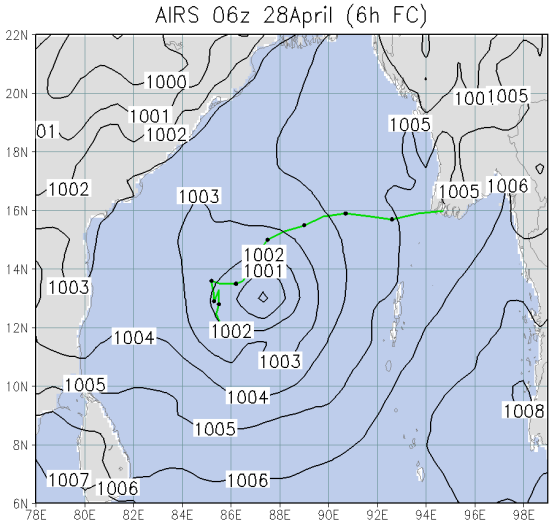
800x600km
Contours
every 1hPa

X observed
cyclone's
center

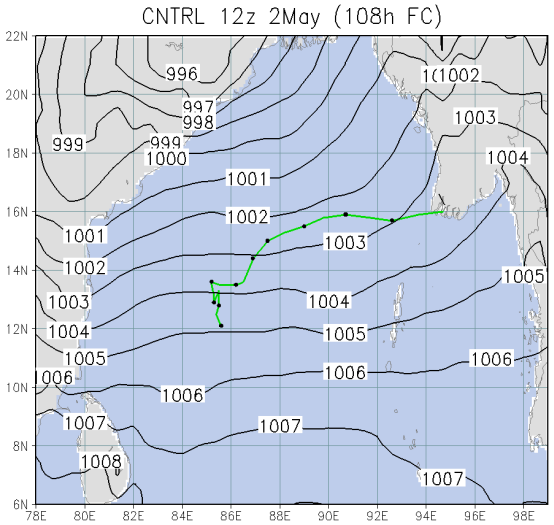
WINDS DO NOT REACH 12m/s
WINDS DO NOT FORM A CLOSED CIRCULATION

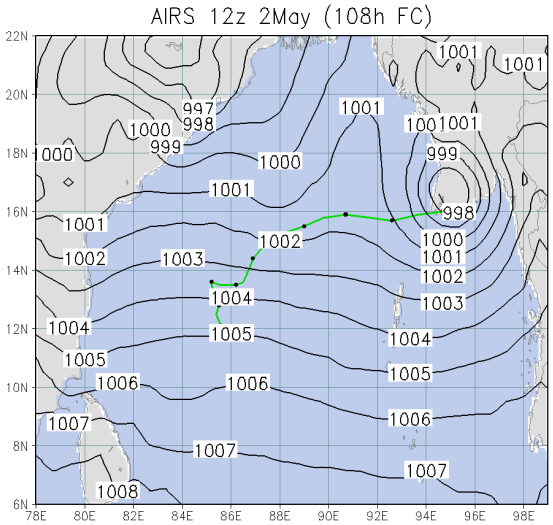
AIRS v5 retrivals impact on TC Nargis analysis





AIRS Analysis Well-defined Cyclone Green: Observed Track





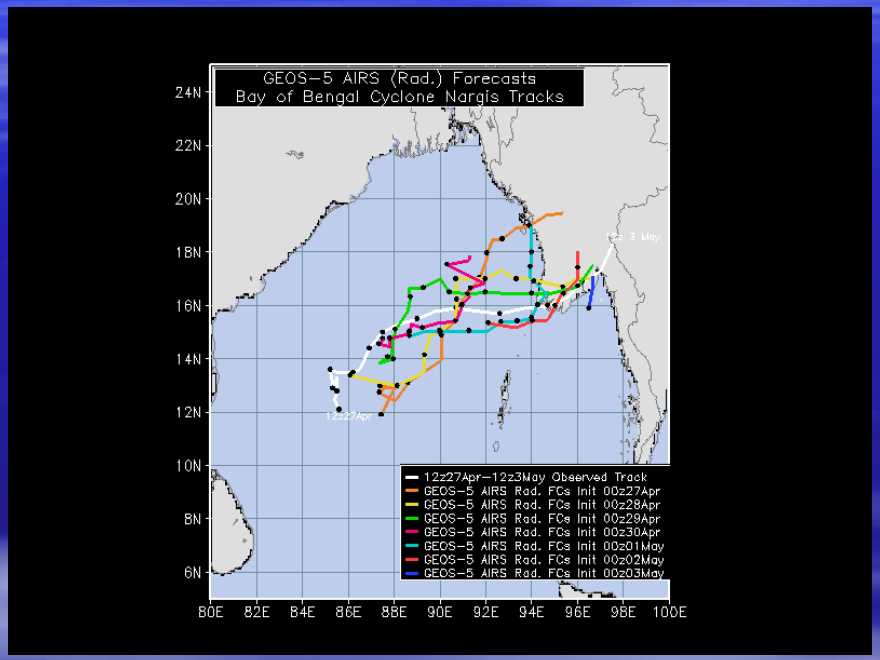
AIRS 108-hour Forecast (slp)

Green: Observed Track

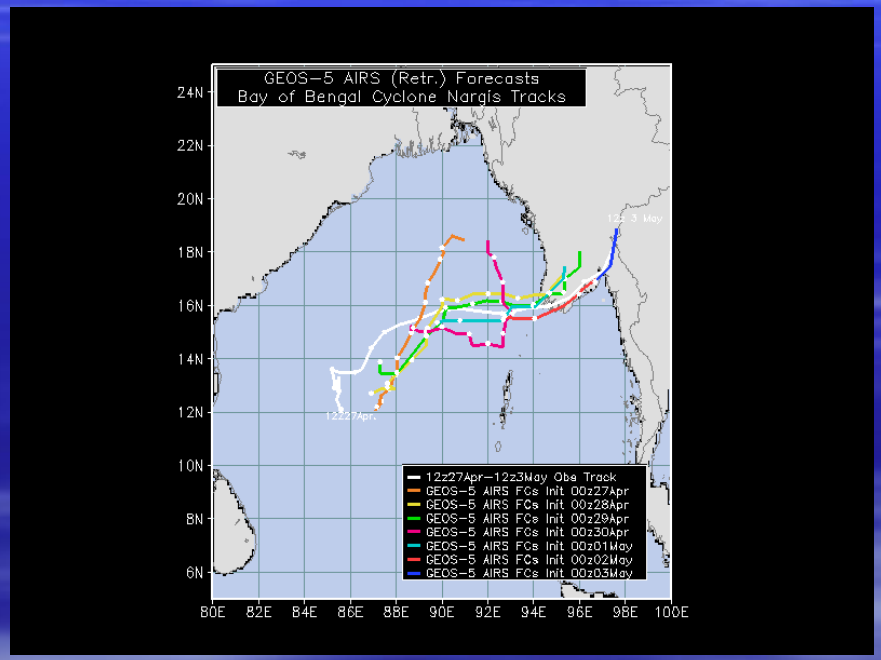
CNTRL Analysis (above)
And forecast (below): No Cyclone

Accurate landfall is produced in the forecasts initialized with AIRS: (Reale et al., 2009, *Geophys. Res. Lett.*)

Large forecast track improvement for tropical cyclone Nargis (2008) consequent to AIRS v5 cloudy retrieval assimilation, compared to assimilation of clear-sky radiances



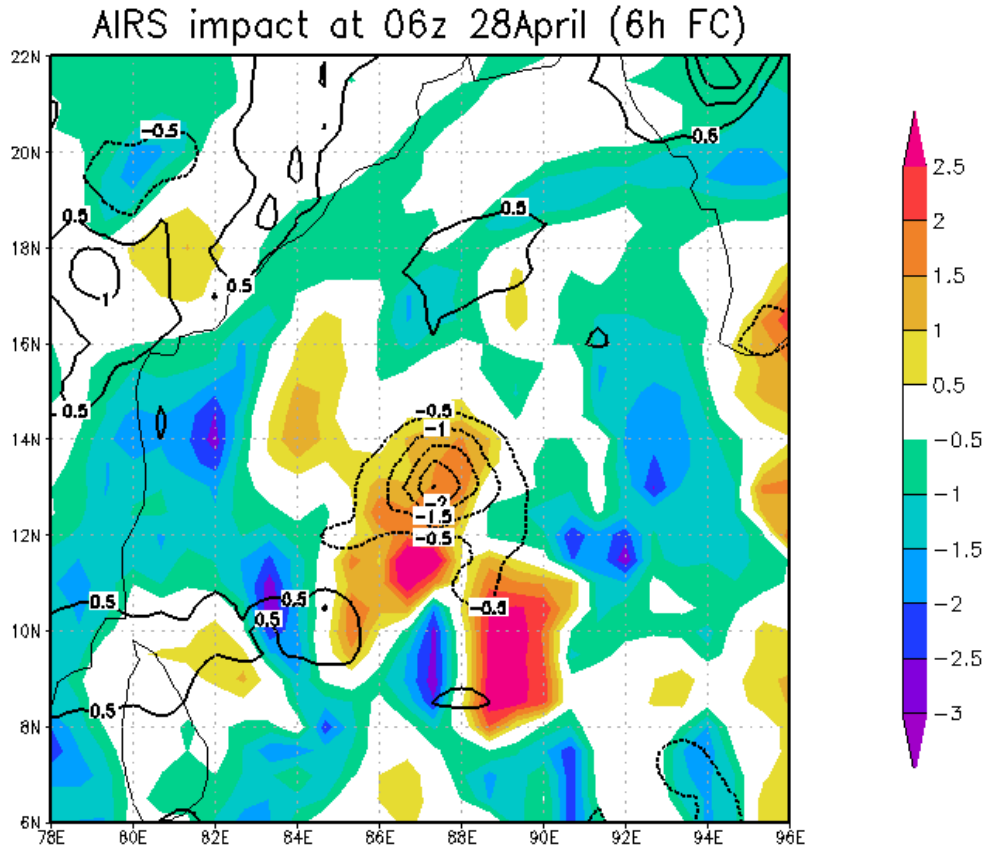
AIRS clear-sky radiances



AIRS v5 cloudy retrievals

5 out of 7 forecasts initialized from the improved analyses have a displacement error at landfall of about 50km (Reale et al., 2009, *Geophys. Res. Lett.*)

How AIRS retrievals improve the analysis of a TC?



The localized, intense Upper-Level heating induced by AIRS data in correspondence to organized convection deepens the low-level cyclonic circulation of TC Nargis

Shaded: 200 hPa AIRS minus CNTRL temp anomaly
Contour: AIRS minus CNTRL slp anomaly (Reale et al., 2009)

Previous work showing improvement in TC cloud/moisture distribution caused by AIRS v5 retrievals

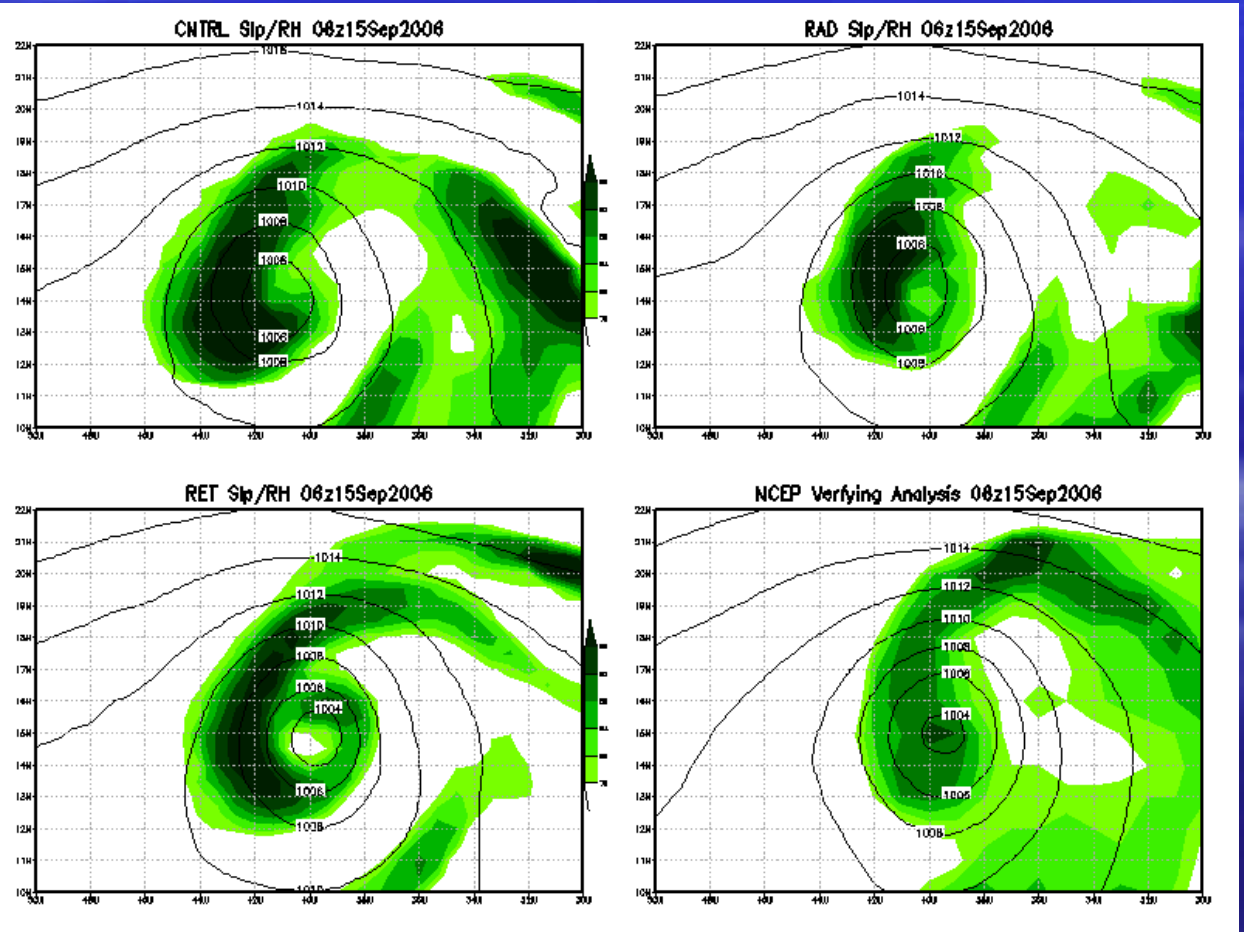
Example: **TS Helene Analysis at 06z 15Sep2006**

30 hours before becoming a hurricane

800 hpa relative humidity, sea level pressure (hPa)

CNTRL

RETRIEVALS
Produce an Eye-like feature



RADIANCES
Do NOT produce an Eye-like feature

NCEP Operational Analyses, Very poor

Two previously published AIRS impact studies on extreme precipitation prediction with the GEOS-5 Comparing AIRS clear-sky radiances against retrievals.

- 3 TCs selected in different seasons, Atlantic and Indian Oceans
- Pakistan Floods (2010)

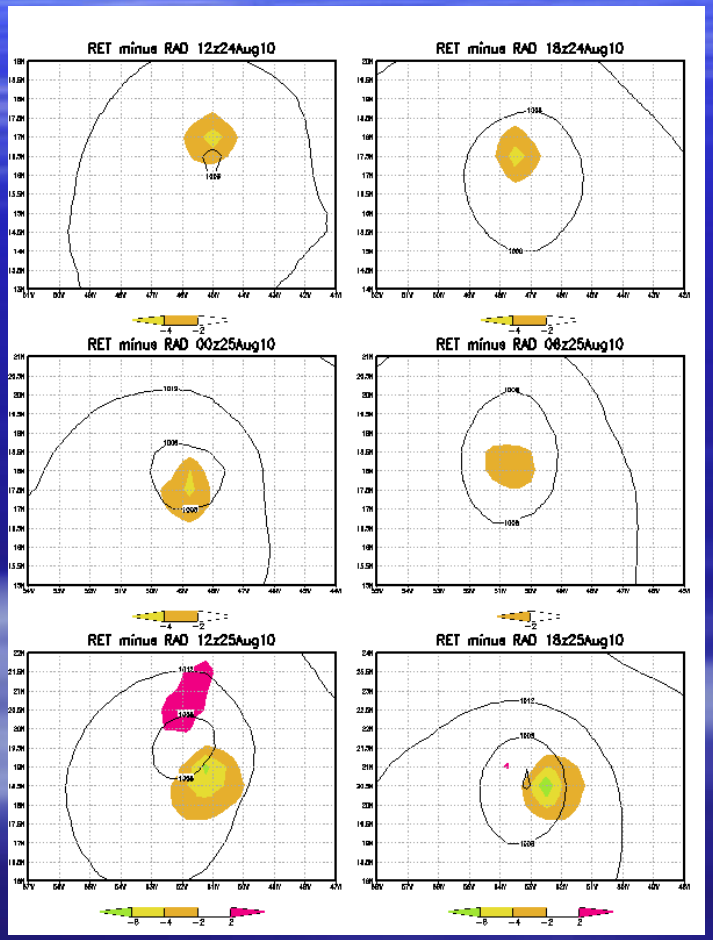
Zhou, Y., W. K. Lau, O. Reale, R. Rosenberg, 2010: AIRS Impact on precipitation analysis and forecast of tropical cyclone in a global data assimilation and forecasting system.
Geophys. Res. Lett., **37**, L02806, doi.1029/2009GL041494

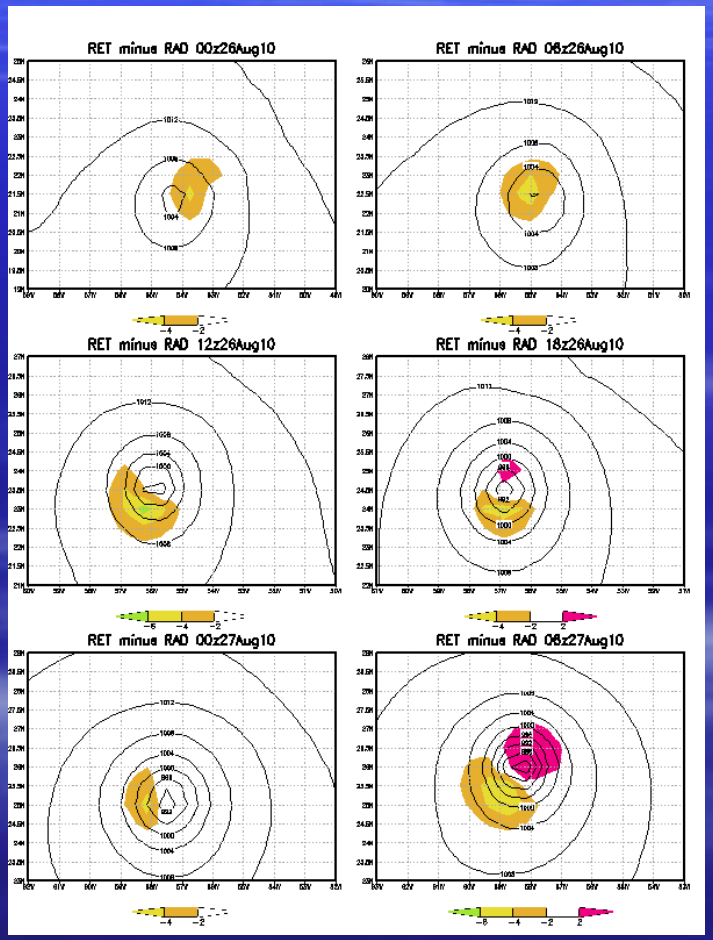
Reale, O., W. K. Lau, J. Susskind, R. Rosenberg, 2011: AIRS Impact on analysis and forecast of an extreme rainfall event (Indus River Valley, Pakistan, 2010) with a global data assimilation and Forecast system.
J. Geophys. Res., 117, D08103, doi:10.1029/2011JD017093.

NEW: Hurricanes Danielle and Earl (2010)

- Danielle (21-30 Aug 2010) reached Cat 4, underwent a sharp northeastward turn followed by increased speed and rapid ET transition
- Earl (25 Aug – 4 Sep 2010) reached Cat 4, made landfall as Cat 1 in Nova Scotia, Canada
- GEOS-5 v7.2 analyses improve tremendously as result of assimilating AIRS v5 retrievals, as opposed as clear-sky radiances, particularly the Danielle case.
- Corresponding forecasts show improvement in both intensity and track

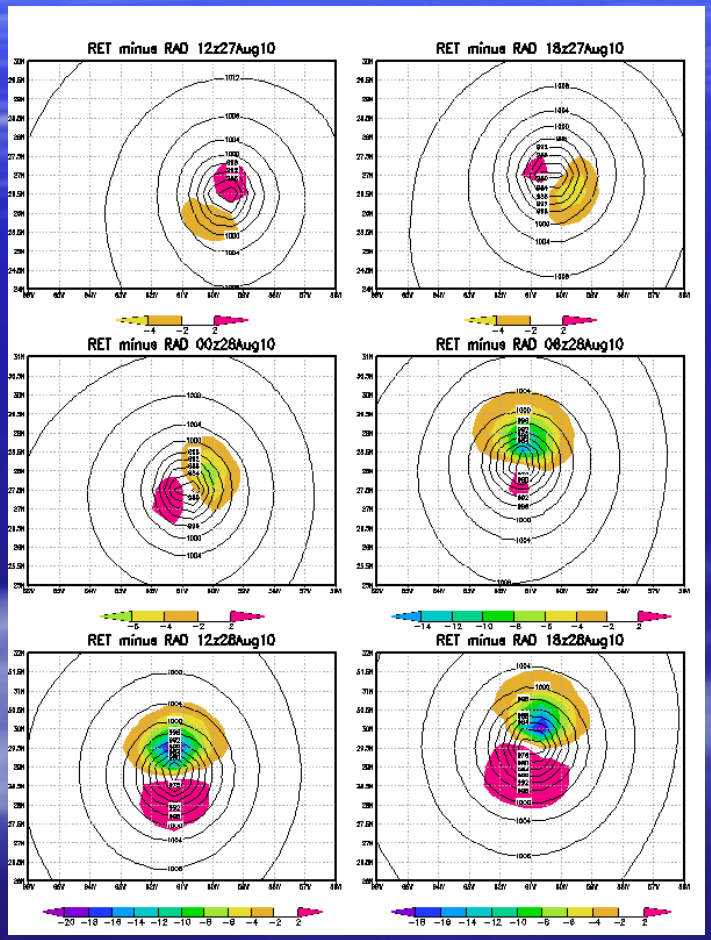
Hurricane Danielle 24Aug-27Aug
GEOS-5 Analysis

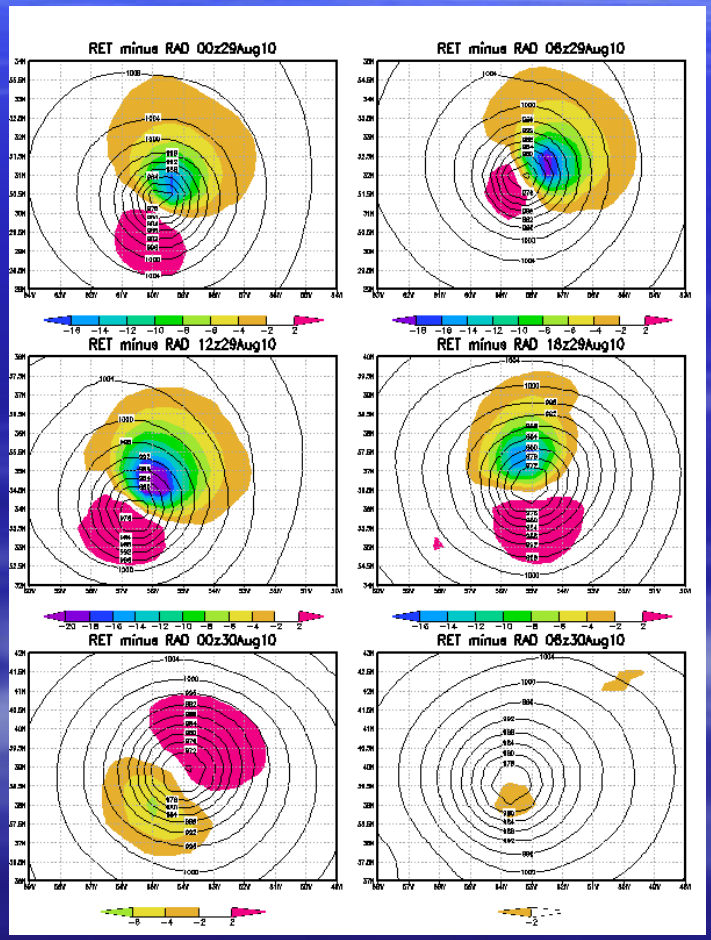




Solid: RAD; Shaded RET minus RAD

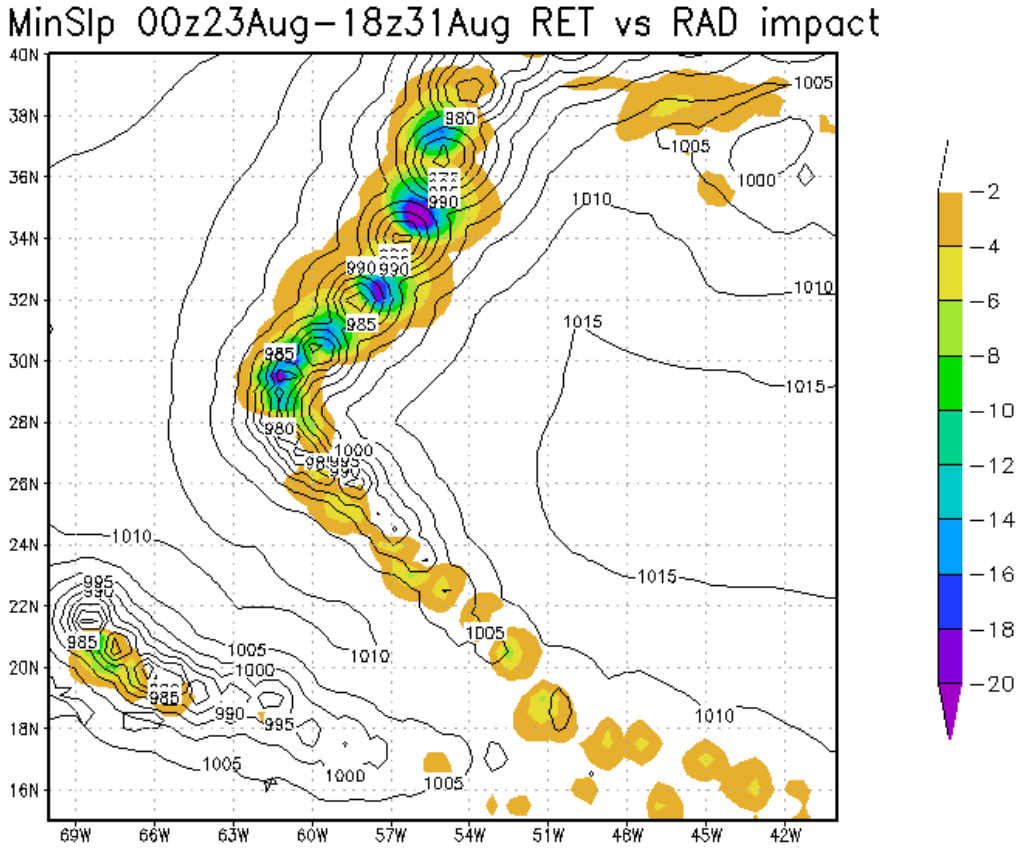
Hurricane Danielle 27Aug-30Aug
GEOS-5 Analysis





Solid: RAD; Shaded RET minus RAD: differences up to 20 hPa

Analysis of Danielle from 00z23Aug to 18z31Aug RET consistently produces deeper center pressures than RAD (up to **20 hPa**)



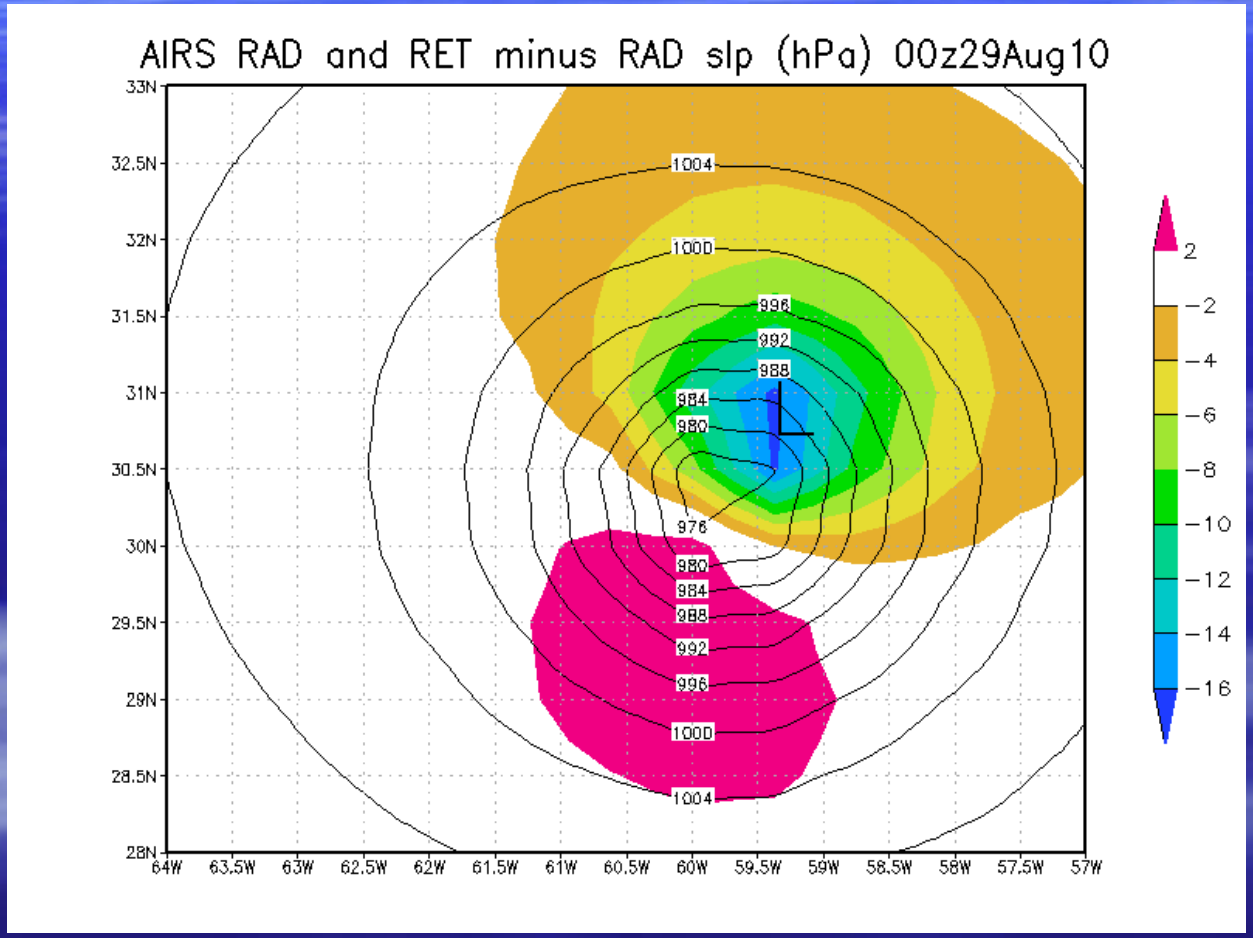
Minimum Analyzed center pressure:
967 hPa (RAD)
957 hPa (RET)
942 (OBS)

Min RET minus RAD diff -20.8 hPa

Max RET minus RAD diff 0.5 hPa

Solid: RAD; Shaded RET minus RAD

Danielle at a time of sharp NE-ward recurvature and acceleration (00z29Aug2010) (**optimal** AIRS RET analysis)



ANALYSIS

Contour:
RAD Slp (hpa)

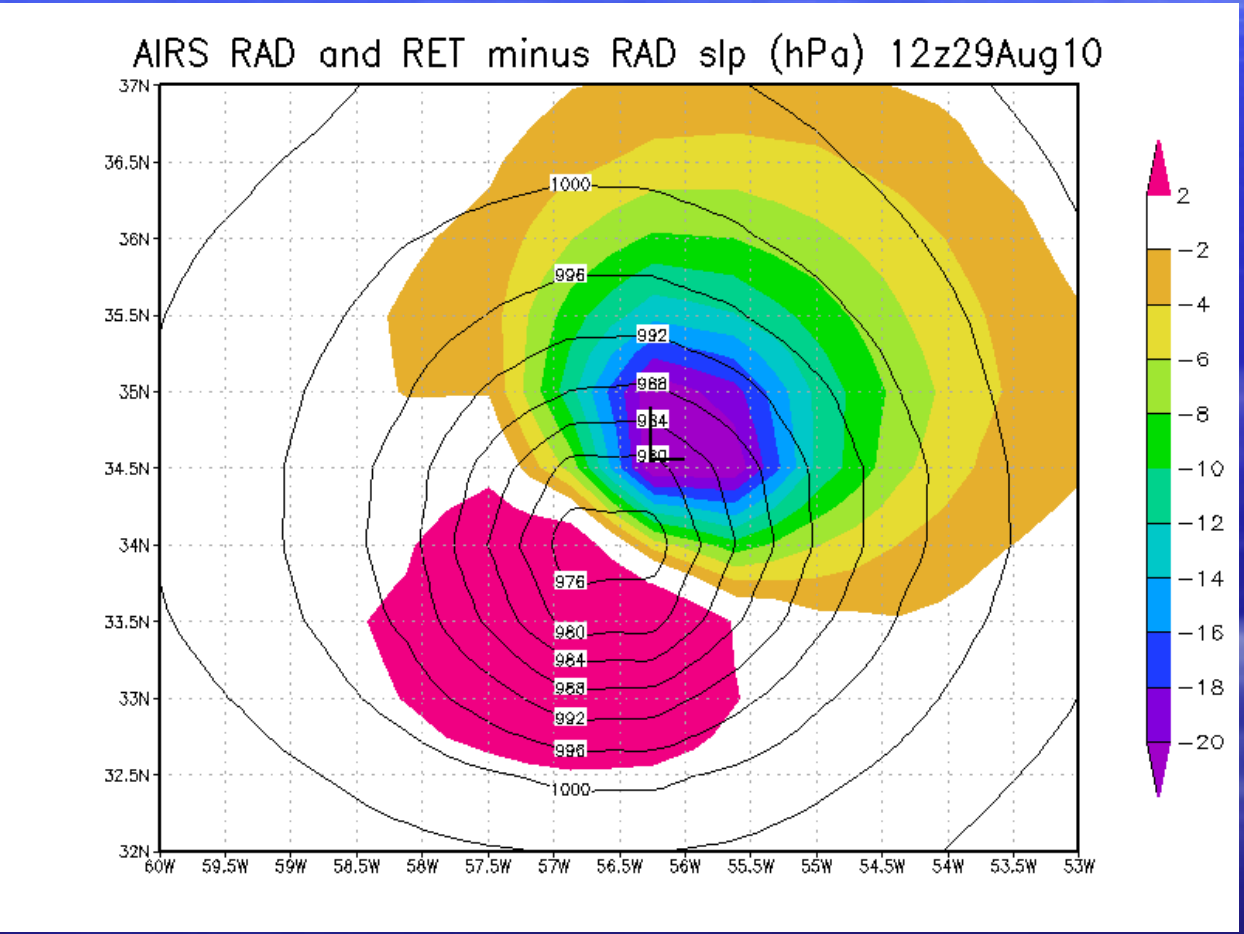
Shaded:
RET minus RAD

L Obs center

RAD 973 hPa
RET 959 hPa
OBS 958 hPa

RET moves the analyzed center towards the right direction

Danielle keeps accelerating NE-ward (12z29Aug2010) (**again, optimal** AIRS RETanalysis)

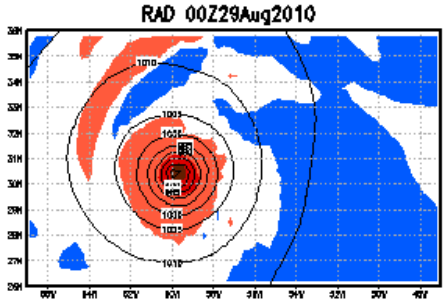


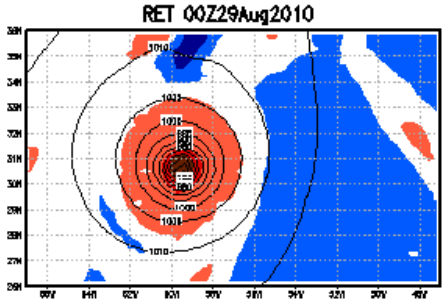
Again RET moves the center towards the right direction

Comparing Danielle structure in analyses (00z29Aug)

RAD
Slp and
850 vort

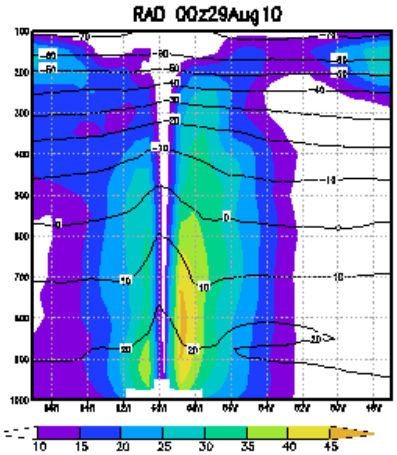
RET
Slp and
850 vort

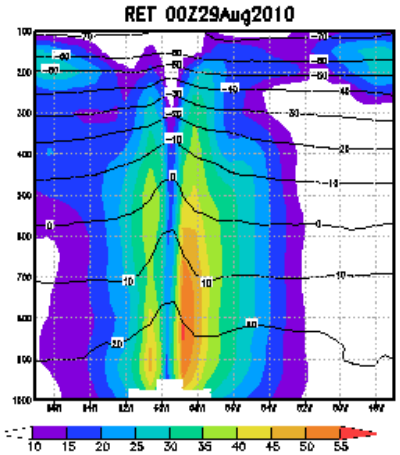




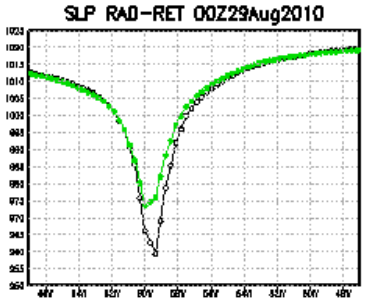
RAD
Wind
And Temp
(30.5N)

RET
Wind
And Temp
(30.5N)

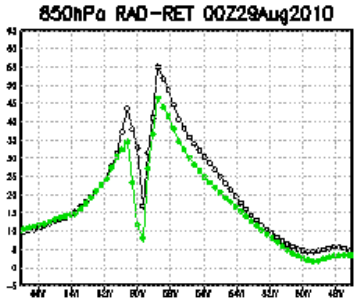




RAD slp
RET slp

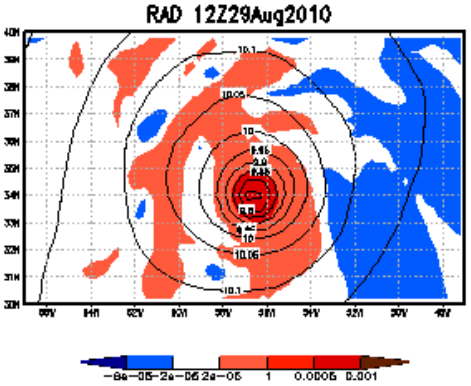


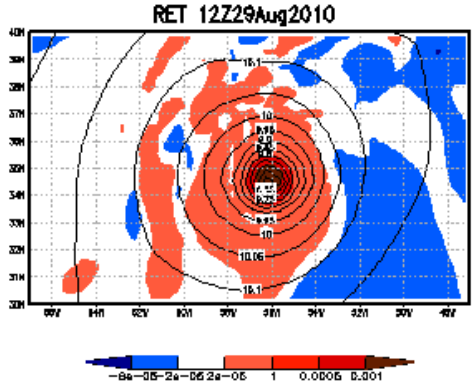
RAD 850 hPa wind
RET 850 hPa wind



Comparing Danielle structure in analyses (12z29Aug)

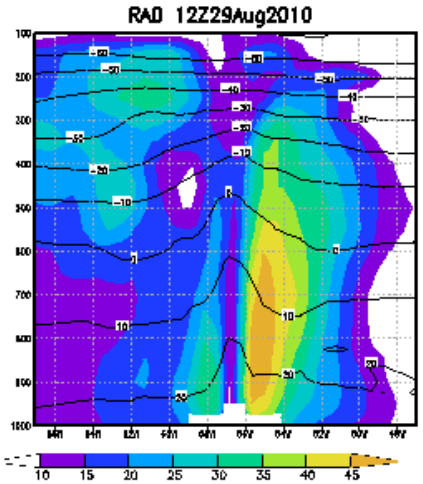
RAD
Slp and
850 vort

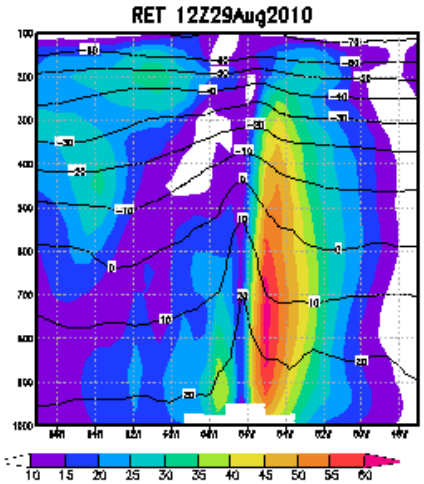




RET
Slp and
850 vort

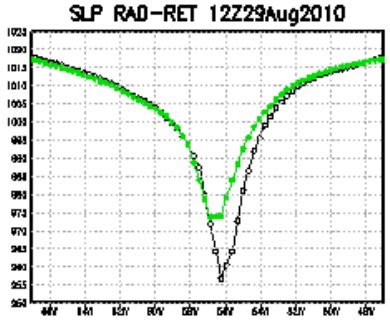
RAD
Wind
And Temp
(34N)

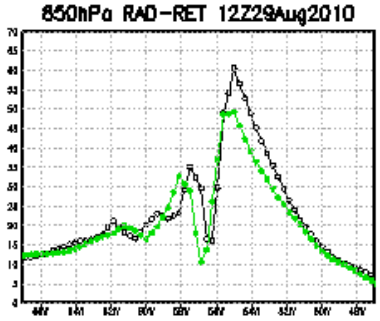




RET
Wind
And Temp
(34.5N)

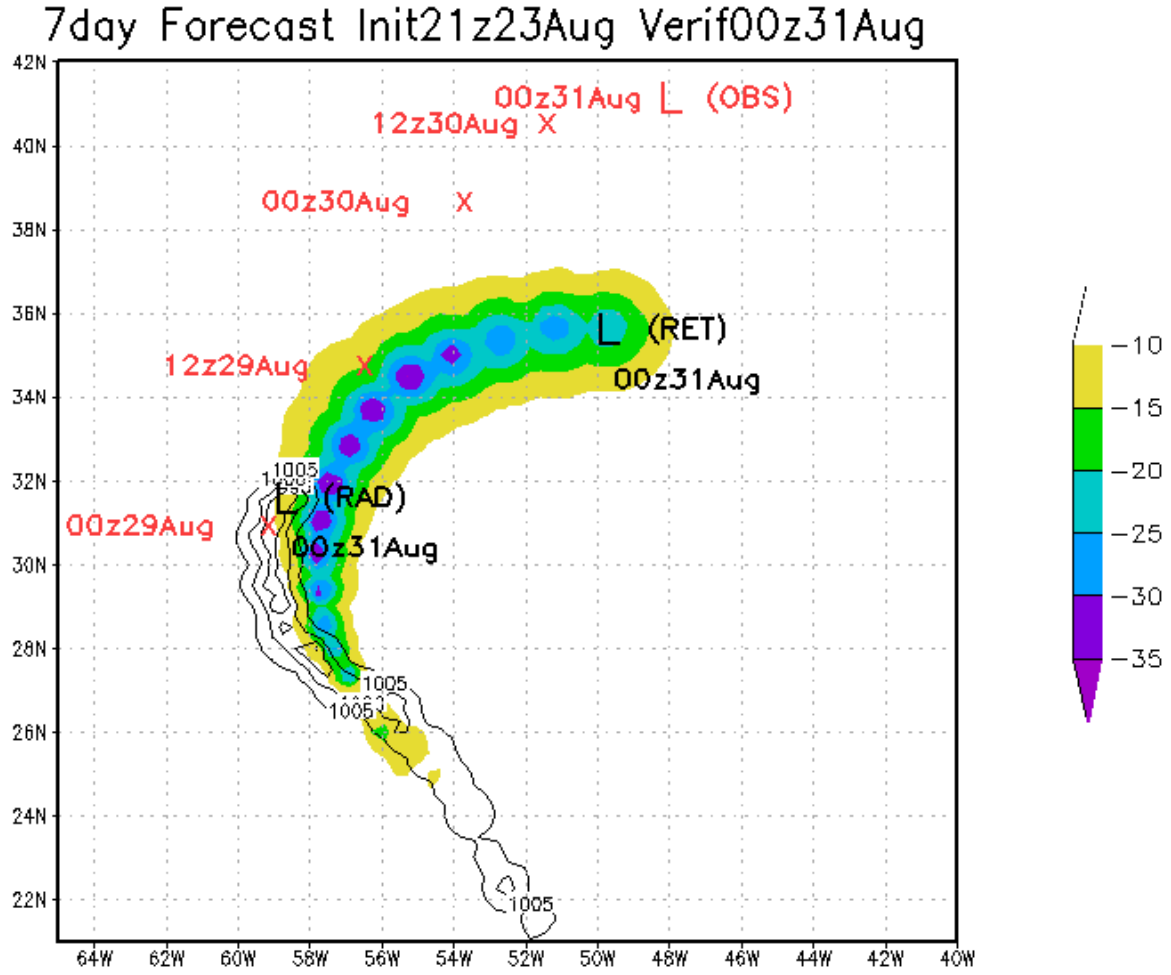
RAD slp
at 34N
RET slp
at 34.5N





RAD 850 hPa wind
at 34N
RET 850 hPa wind
at 34.5N

Example of a **7-day forecast** in which BOTH intensity and forecast are improved



RAD error
770 km

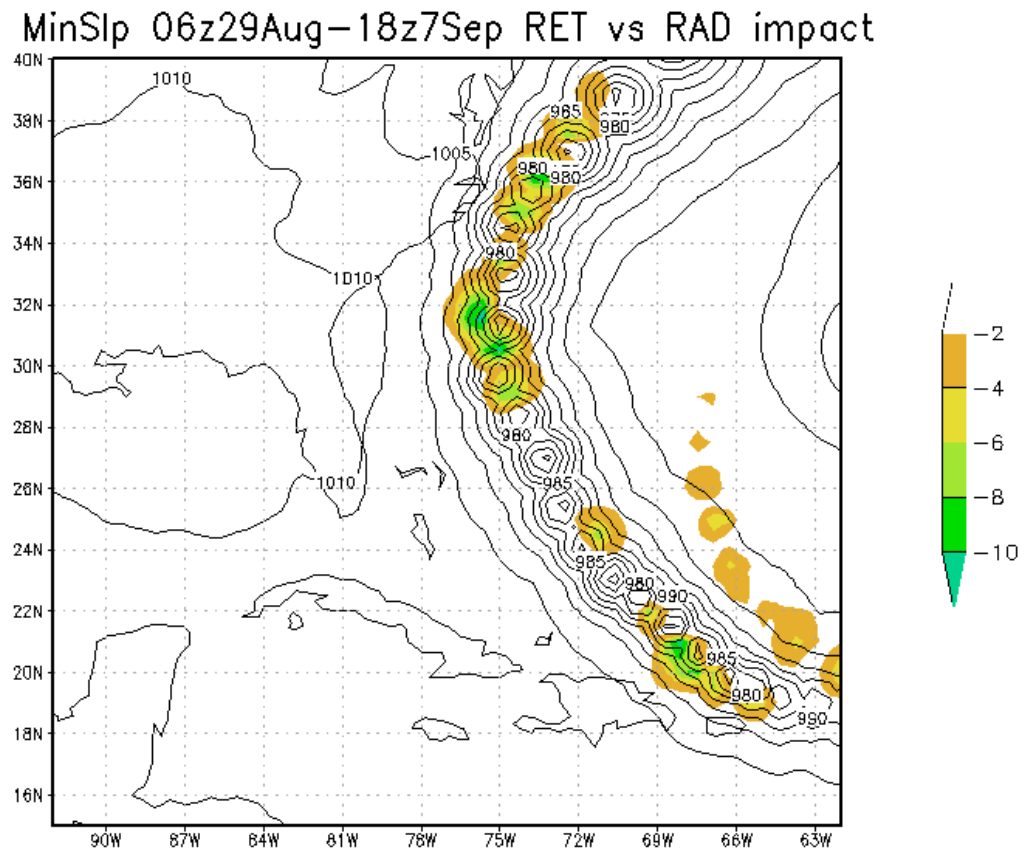
RET error
340 km

X obs center
L obs center
at 00z31Aug

L RET/RAD centers
at 00z31Aug

Solid RAD min slp
Shad RET minus RAD

Analysis of Earl
RET consistently produces deeper center pressures than RAD (up to **10 hPa**)



Minimum Analyzed center pressure:

962 hPa (RET)
964 hPa (RAD)
931 hPa (OBS)

Min RET minus RAD diff -11.4 hPa

Max RET minus RAD diff 0.2 hPa

QUESTION: were the previous results good because the representation of TCs in the previous GEOS-5v2 was not optimal?

- The experiments suggest that with the GEOS-5v7.2 increased ability to produce realistic TC structures, the impact of AIRS v5 retrievals on the GEOS-5 analysis becomes even more prominent
- The improved analyses lead to better track and intensity forecasts, particularly for transitioning tropical cyclones
- When the difference in RAD and RET analysis is small, the impact on the forecast is negligible

Conclusions

- Previous data assimilation experiments with GEOS-5 v2, comparing the impact of AIRS v5 retrievals and clear-sky radiances, produced for boreal winter, spring, three summers and fall conditions, had shown that the overall impact on forecasts skill of retrievals is higher than the corresponding impact of radiances in every season and every year
- 3 GRL articles and 1 JGR article had been published
- However, GEOS-5v2 lacked the ability to produce realistically deep TC structures
- On the contrary, the more recent GEOS-5 v7.2 produces very realistic TCs.
- New AIRS impact studies focused on tropical cyclones show that improvements on tropical cyclone analysis are even larger than with previous model versions.
- This suggests that increased realism in the TC representation in models can benefit even more by AIRS cloud-derived information

Ongoing and future Work

- Research under current **grant** (June 2011-2014) on ``AIRS impact on processes affecting **Tropical Cyclone structure** in global models'' indicate great potential for improving intensity forecast in global models.
- AIRS impact on Tropical Cyclones in the GEOS-5 is being studied over the Atlantic, Indian and Pacific Oceans with focus on 2010 and (future) 2011 seasons
- Experiments with AIRS version 6 will start soon

Acknowledgments

- **Dr. Ramesh Kakar** *for support to previously funded proposal ``Relationships among precipitation characteristics, atmospheric water cycle, climate variability and change'' (PI:* Dr. W. K. Lau)
- **Dr. Ramesh Kakar** *for support to* ***currently funded*** *proposal ``Using AIRS data to understand processes affecting Tropical Cyclone structure in a Global Data Assimilation and Forecasting Framework'' (PI:* Dr. O. Reale)
- **Dr. Tsengdar Lee** for generous allocations of NASA High End Computer resources
- **AIRS team** at JPL and the **Sounder Research Team** at NASA GSFC

National Aeronautics and Space Administration

AIRS-related articles published by this team

Reale, O., J. Susskind, R. Rosenberg, E. Brin, E. Liu, L. P. Riishojgaard, J. Terry, J. C. Jusem, 2008: Improving forecast skill by assimilation of quality-controlled AIRS temperature retrievals under partially cloudy conditions. Geophysical Research Letters, 35, L08809, doi:10.1029/2007GL033002.

Reale, O., W. K. Lau, J. Susskind, E. Brin, E. Liu, L. P. Riishojgaard, M. Fuentes, R. Rosenberg, 2009: AIRS Impact on the Analysis and Forecast Track of Tropical Cyclone Nargis in a global data assimilation and forecasting system. Geophysical Research Letters, 36, L06812, doi:10.1029/2008GL037122.

Reale, O., W. K. Lau, K.-M. Kim, E. Brin, 2009: Atlantic tropical cyclogenetic processes during SOP-3 NAMMA in the GEOS-5 global data assimilation and forecast system. Journal of the Atmospheric Sciences, 66, 3563-3578.

Zhou, Y., W. K. Lau, O. Reale, R. Rosenberg, 2010: AIRS Impact on precipitation analysis and forecast of tropical cyclones in a global data assimilation and forecasting system. Geophysical Research Letters, 37, L02806, doi.1029/2009GL041494.

Reale, O., K. M. Lau, J. Susskind, and R. Rosenberg, 2012: AIRS impact on analysis and forecast of an extreme rainfall event (Indus River Valley, Pakistan, 2010) with a global data assimilation and forecast system, J. Geophys. Res., 117, D08103, doi: 10.1029/2011JD017093.